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PATTERNS OF SUSPENDED PARTICLE TRANSPORT IN A MISSISSIPPI TIDAL MARSH SYSTEM[1]

COURTNEY T. HACKNEY[2] AND ARMANDO A. DE LA CRUZ
Department of Biology, Mississippi State University, Mississippi State, MS 39762

ABSTRACT The flux of suspended particulate organic detritus (POD) and suspended inorganic detritus (PID) was studied during ten diurnal tidal periods (24-hour) and three semi-diurnal tidal periods (12-hour) between May 1975 and April 1976. The concentration of POD ranged from 1.50 to 19.79 mg/l, while the PID ranged from 3.20 to 99.61 mg/l. There was a net export of POD during four of 13 tidal periods and a net export of PID during five tidal periods. There was a total net movement of 39.32 and 292.51 kg of POD and PID, respectively, into the marsh. On an annual basis, this is equivalent to the addition of 168 $g/m^2/yr$ of detrital material to the marsh.

The predictability of POD and PID concentration in the water was good (r^2 of 57.9 and 58.1%) during ebb tide based on nine biological and physical variables. The ratio of POD to total suspended material was 15.9% and constant during the year at all concentrations.

Although the marsh may not be an important source of carbon for the estuary, data indicate that the marsh may regulate the concentration of suspended detritus in the nearby bay by releasing detritus when the detritus concentration in the water is low and by accumulating detritus when this concentration is high.

INTRODUCTION

The high productivity of tidal marshes and the presence of high concentrations of particulate organic matter in adjacent coastal waters has led to the conclusion that tidal marshes export much of the carbon fixed by vascular plants on the marsh. An early study (de la Cruz 1965) of the transport of particulate organic detritus substantiated this initial conclusion. Recent investigations, however, suggest that the export of organic carbon from tidal marshes may not be a general phenomenon (Nadeau 1972; Heinle and Flemer 1976; Shisler and Jobbins 1977; Woodwell et al. 1977), while other transport studies support the traditional view of a net detrital export (Heald 1969; Moore 1974; Settlemyre and Gardner 1977). Some variation in detritus transport should be expected among tidal marsh systems which differ in their vegetation, tidal regime (diurnal or semi-diurnal), tidal range, freshwater input from rivers and geographic orientation with respect to the nearby open water and prevailing winds. Factors which might enhance the movement of particulate material on and off the marsh have not been evaluated with respect to the concentration of particulate material and its subsequent transport in the marsh system.

This study examines the concentration of suspended particulate material (organic and inorganic) in a tidal creek draining an irregularly flooded *Juncus* marsh in Mississippi. The effects of 13 biological and physical variables on the concentration of detrital material during the ebb and flood stages of the tidal cycle were determined. In addition, the role of tidal marshes and particulate organic detritus in the productivity of estuaries was reexamined based on the current investigations and on the basis of recent works by other investigators.

STUDY AREA

The study area is located on the southeastern end of a deltaic island deposited by the Jourdan River. The marsh island is on the western side of St. Louis Bay in Hancock County, Mississippi (Figure 1). The study area included 5.84 ha of watershed drained by a small creek which in turn empties into Catfish Bayou. The creek channel is 95 m long, and 4 to 6 m wide along most of its length. The creek channel has steep banks, but is not deeper than 1 m during mean low tide. The upper reaches of the creek are shallow (less than 20 cm) during low tide and are characterized by very soft bottom sediments, while areas of the creek near the mouth have firm mud substrates. The creek never drains completely, even during the lowest tides. A small bar at the mouth of the creek retains water in the creek when the water level is lower in the adjoining bayou.

MATERIALS AND METHODS

Hydrology

A survey of the study area was made on February 21 and 22, 1975, and the elevation of the marsh was determined to the nearest 2.6 cm using standard survey equipment. The watershed of the study creek was determined by finding the highest point between the study creek and other nearby bodies of water. Where no elevated areas existed, the watershed was estimated by including half of the area between the study creek and the body of water in question.

The volume of water moving in and out of the creek was

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[2] Present address: Department of Biology, University of Southwestern Louisiana, Lafayette, Louisiana 70504.

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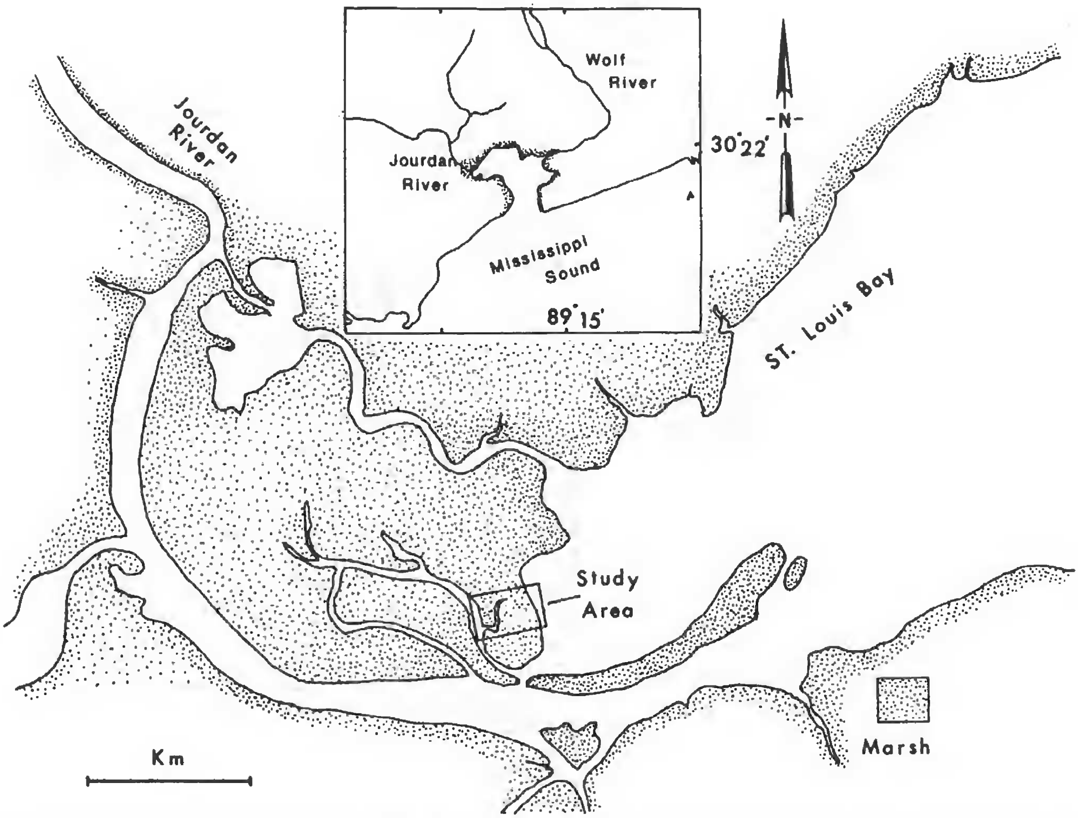

Figure 1. The western side of St. Louis Bay showing the marsh island on which the study area is located. Insert shows the location of the Wolf and Jourdan rivers relative to St. Louis Bay.

determined by two methods. When the tidal height was above the creek banks, adequate water currents were present and a current meter (Weathermeasure Corporation Model F-582) was used to directly measure water flow. The current was measured approximately 20 cm below the surface. The current meter was accurate to ± 0.02–0.05 m/s within the current range observed. The volume of water was calculated by multiplying the current velocity by the cross sectional area of the creek at the point of measurement. The cross sectional area of the creek was determined by measuring the depth of the creek every 0.5 m across the mouth of the creek and graphically producing an area of the mouth's cross section for any level of water based on a permanent tidal gauge in the creek. For every unit (cm) increase or decrease of the tidal height the cross sectional area of the creek changed correspondingly. When the water level was below the creek bank, no measurable current was present. Water movement was determined by changes in the volume of water present in the creek. This was determined by measuring the cross sectional area of the creek at representative points and determining the volume of the creek at any given tidal height, using a permanent tidal gauge located within the creek as a reference point. Thus, a 1-cm change of water level was accompanied by a known volume change at any point in the tidal cycle.

The volume of water entering or leaving the creek is important in the calculation of net import or export of suspended materials during a tidal cycle. The weak diurnal tides along the Mississippi Gulf coast seldom return to the same level at the end of a tidal cycle. A suspended particulate matter budget which does not account for this difference would be inaccurate, although over many collections the bias is not important. An example of the calculations used to determine this correction factor may be found in Hackney (1977). Values reported here are the actual transport values although the corrected values are also reported for seasonal comparisons.

It is assumed in all the calculations that the current was uniform across the entire cross section of the creek, and that the concentration of suspended particulate material passing the collecting station was uniform during the specified time interval and with respect to depth and width.

During the study, salinity, temperature and dissolved oxygen concentration of the water were measured *in situ* 20 cm below the surface every hour. Salinity was measured with a Yellow Springs S–C–T (salinity-conductivity-temperature) meter (Model 33), precise to ±0.7‰. Dissolved oxygen was measured with a Yellow Springs oxygen meter (Model 54), precise to ±1%. Temperature was measured with a thermister attached to the oxygen meter and precise to ±1%.

Three 1.22 m^2 pull-up traps (Higer and Kolipinski 1967) with 3.1 mm mesh were placed in the creek in March 1975. One net was installed along the south end of the creek approximately 22 m from the mouth, while the second and third traps were placed in the middle of the creek 70 and 92 m from the mouth. Collections were always made during ebbing tide at approximately the same water height during a tidal cycle as indicated by a permanent tidal gauge. One collection consisted of pulling each of the three nets on two successive days following the transport study. No reduction in catch was noted on the second day. These data provided information on the numbers and biomass of organisms in the creek during each transport study. A measure of the movement of organisms into and out of the creek was obtained by placing a 3.1 mm mesh bag seine across the entrance of the tidal creek. The bag stretched across the creek from the surface to the bottom. Organisms were removed during high slack tide and low slack tide. Although this technique was selective for smaller organisms (crabs and shrimp), it provided information on animal movements into and out of the creek.

Suspended Particulate Material

Water was collected 20 cm below the surface every 2 hours during each of 13 tidal periods from May 1975 to April 1976. The collection for January 1976 was made on February 5, 1976. Samples were collected from two consecutive semi-diurnal (12-hour) tidal periods on September 19 and 20, 1975, and one on February 5, 1976. Water was collected in 4-liter plastic jugs and preserved in 1% formalin solution to prevent agglutination and bacterial decomposition of the suspended particulate organic detritus. Preservation did not alter the analytical results since prior testing with preserved and unpreserved samples did not differ with respect to combustible carbon (ANOVA [analysis of variance] at $\alpha = 0.05$).

Water samples were brought to the laboratory and filtered through a Gelman Type A glass filter (0.3 μm porosity) following the procedure of Golterman (1969), with modification for the glass filters. The results are reported as the weight of oxidizable material (particulate organic detritus, POD) per liter of water and as the weight of nonoxidizable material (particulate inorganic detritus, PID) per liter of water. Golterman (1969) notes that the loss of bound water from clays in the PID is negligible. Appropriate corrections were made for the addition of formalin and for filter weight loss during ashing.

RESULTS

Transport

The concentration of total suspended particulate material ranged from 4.6 to 119.4 mg/l. The oxidizable fraction, suspended POD, ranged from 1.5 to 19.7 mg/l while the PID ranged from 3.2 to 99.6 mg/l. Concentrations between 12.0 and 36.0 mg/l, 2.0 and 4.5 mg/l and 6.0 and 30.0 mg/l for total suspended material, organic fraction and inorganic fraction, respectively, were more common.

There was a net export of suspended POD during four of the 13 tidal periods and a net export of PID during five tidal periods (Table 1). Because of the variability in tidal flushing, the amount of suspended materials exchanged varied greatly from tidal cycles in which there was little net exchange to cycles in which more than 167 kg of suspended materials were exchanged (Table 1). The concentration of both POD and PID was always highest near low tide (Figure 2). Very little water exchange occurred during the lowest part of the tidal cycle. Incoming water filled only the tidal creek channel. Increased water flow and volume of water moving into or from the marsh occurred during the flood portion of the tidal cycle. Thus, actual exchange was determined more by concentrations of detritus at higher tide levels; for example, from 1500 to 2000 hours and from 0400 to 1200 hours (Figure 2) during the May 1975 sampling.

There was a total net flux of 39 kg of POD and 293 kg of PID into the marsh during the 13 tidal cycles studied. Most of the tides which exported detritus occurred during the summer, while detritus was imported during most of the rest of the year. There were 385 tidal cycles (Tide Tables 1975, 1976) during the 12-month study of detrital flux. Data from the 13 tidal cycles studied were integrated based on this information. More than 1164.5 kg of POD and 8662.8 kg of PID were estimated to have been added to the 5.84 ha area of marsh drained by the small tidal creek. This is equivalent to the addition of 168 g of detrital material per m^2 per year.

Fauna

Thirty-two species of fish and four invertebrate species were collected. The winter fauna was dominated by *Fundulus grandis* and *Fundulus confluentus*. During the spring and summer *Brevoortia patronus* and *Anchoa mitchilli* were very abundant. *Palaemonetes pugio* was present all year. For more details on the fauna of this area see Hackney (1977).

Predictability

The export or import of detritus depends on its concentrations in the water during the ebb and flood tide and on the difference between these two values, assuming equal water volume transport. Jackson (1964) found that

TABLE 1.

Summary of particulate detritus budget expressed as kilograms per tidal cycle.

	Organic Particulate Transport			
Date	Out	In	Actual Net	Compensated Net
5/27/75	46.603	31.931	-14.670	-14.786
6/28/75	25.839	6.587	-19.252	- 2.397
7/22/75	22.623	29.897	+ 7.274	- 7.697
8/30/75	47.364	28.899	-18.465	-10.087
9/19/75	10.370	11.215	+ 0.845	+ 1.226
9/20/75	15.915	18.075	+ 2.160	+ 5.700
10/24/75	20.127	35.665	+15.538	+16.257
11/21/75	9.256	10.452	+ 1.196	+ 1.197
12/23/75	1.348	2.791	+ 1.443	+ 0.603
2/ 5/76	1.624	0.472	- 1.152	- 0.476
2/20/76	15.549	47.475	+31.926	- 1.528
3/26/76	16.529	25.283	+ 8.754	+ 8.603
4/16/76	28.846	52.579	+23.733	+41.833
Totals	261.993	301.321	+39.328	+38.440

	Inorganic Particulate Transport			
Date	Out	In	Actual Net	Compensated Net
5/27/75	112.641	101.406	- 11.235	- 10.978
6/28/75	55.158	16.759	- 38.399	+ 2.761
7/22/75	53.289	75.456	+ 22.167	- 7.926
8/30/75	123.850	54.815	- 69.035	- 53.386
9/19/75	26.237	31.950	+ 5.713	+ 6.793
9/20/75	35.980	49.358	+ 13.378	+ 23.367
10/24/75	61.199	96.547	+ 35.348	+ 38.563
11/21/75	41.367	37.393	- 3.974	- 3.974
12/23/75	4.069	9.313	+ 5.244	+ 2.052
2/ 5/76	4.393	1.403	- 2.990	- 1.063
2/20/76	42.664	178.980	+136.316	+ 55.439
3/26/76	45.121	79.101	+ 33.980	+ 33.525
4/16/76	84.481	250.481	+166.000	+165.998
Totals	690.449	982.962	+292.513	+251.171

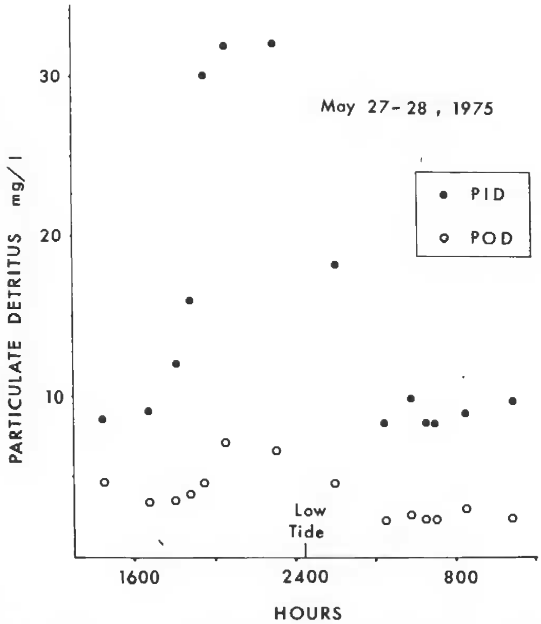

Figure 2. Typical pattern of the concentration of particulate organic detritus (POD) and particulate inorganic detritus (PID) during a tidal cycle.

temperature and tidal range affected the concentration of silt in English estuaries. A multiple regression analysis (Draper and Smith 1966) was used to determine the relationship of the dependent variable POD and the independent variables: temperature, salinity, dissolved oxygen, height of the water in the creek, tidal range, volume of water exported or imported during the day, biomass of organisms in the creek, number of these organisms, weight of plant debris moving in and out of the creek, time of day and time of year. This analysis was done separately for the ebb and flood tides. The analyses were repeated with PID as the dependent variable.

The relative importance of the variables was determined by a subset selection procedure (Hocking and Leslie 1967). This procedure selected tidal height as the most important variable which explained the variation of POD and PID.

During ebb tide, eight variables explained 57.9% of the variability of the POD and 58.1% of the variability of the PID collected during ebb tide (Table 2). Salinity, dissolved oxygen, temperature, day of the year (a measure of seasonal variation) and number of organisms in the creek were also important variables in explaining the variability of POD and PID.

The number of organisms in the creek was also a significant factor in explaining some of the variability of detrital concentration (Table 2). Variable [7] was the biomass of organisms caught in one pull-up trap collection and variable [8] was the number of organisms caught in the same collection. Although these two variables were based on the same data collection they did not exhibit colinearity. Variable [6] was the number of organisms caught in the bag seine which is a measure of their abundance and movement within the creek. Seasonality (time of year), variable [5], was also important because more organisms were in the creek during certain times of the year (Hackney 1977). The influence of salinity, temperature and dissolved oxygen on detrital concentration may also occur when these factors interact with the faunal component of the creek and with the season.

When the same multiple regression analysis and subset selection procedures (using the same variables) were applied to the flood tide, no variable or combination of variables explained much of the variability of POD or PID. Erkenbrecher and Stevenson (1977) noted that ebb and flood

TABLE 2.

Multiple regression model for the concentration of suspended particulate matter during ebb tide and relevant summary statistics.

Particulate Organic Detritus (POD)

y = −1.1897 + 0.0011 [5] + 0.01342 [2] − 0.04927 [4]
+ 0.10759 [3] + 0.00766 [1] + 0.00100 [6]
+ 0.00167 [7] − 0.00052 [8]

r^2	=	0.5701
mean square error	=	0.01996
total sum of squares	=	2.5131
number of observations	=	62

Variable order selected by subset selection procedure and the cumulative r^2 values.

Variable	Cumulative
[1]	0.1995
[2]	0.2418
[3]	0.3122
[4]	0.3920
[5]	0.4649
[6]	0.5336
[7]	0.5607
[8]	0.5791

Particulate Nonorganic Detritus (PID)

y = −6.527 + 0.006292 [5] + 0.04668 [2] − 0.1978 [4]
+ 0.4340 [3] + 0.0456 [1] + 0.00948 [9]
+ 0.00028 [6] + 0.01082 [7] − 0.00334 [8]

r^2	=	0.6144
mean square error	=	0.55018
total sum of squares	=	14.1940
number of observations	=	62

Variable order selected by subset selection procedure and the cumulative r^2 values.

Variable	Cumulative
[1]	0.3083
[9]	0.3601
[4]	0.3959
[3]	0.4212
[5]	0.4739
[8]	0.5811
[7]	0.5940
[8]	0.5811
[7]	0.5940

waters had distinctly different characteristics in a South Carolina tidal creek and that different biotic and abiotic factors were needed to explain the microbial concentration during ebb and flood tides.

The source of suspended particulate detritus appears to be the same for material in ebb and flood waters since no difference between the ratio of particulate organic detritus to total suspended material was noted. A simple linear regression applied to these combined data produced an r^2 of 0.952 for N = 135 (Figure 3). The resultant model (Y = 1.21 + 0.15874X, where Y is the POD and X is the total suspended material) provides a high degree of predictability. The organic material was 15.87% of the total during the study period no matter how high or low the total suspended concentration was in the water. Thus, the similarity of the predictive models for POD and PID is not surprising. The sediment on this marsh contains from 4.9 to 13.0% oxidizable material (Hackney and de la Cruz 1978) while the intact decaying plant material found on this marsh contains 68 to 93% oxidizable materials (Hackney 1977). This seems to indicate that the source of the suspended detrital material is not directly from decomposition of dead plant material. The similarity between the organic ratio of particulate material in the marsh sediment and that of the suspended detritus may indicate that the source of marsh sediment is primarily through the deposition of suspended material.

DISCUSSION

Existing tidal transport studies of particulate organic detritus do not agree on either the net directional movement or on the percent of the overall vascular plant productivity in this movement. Estimates vary from near 50% net export

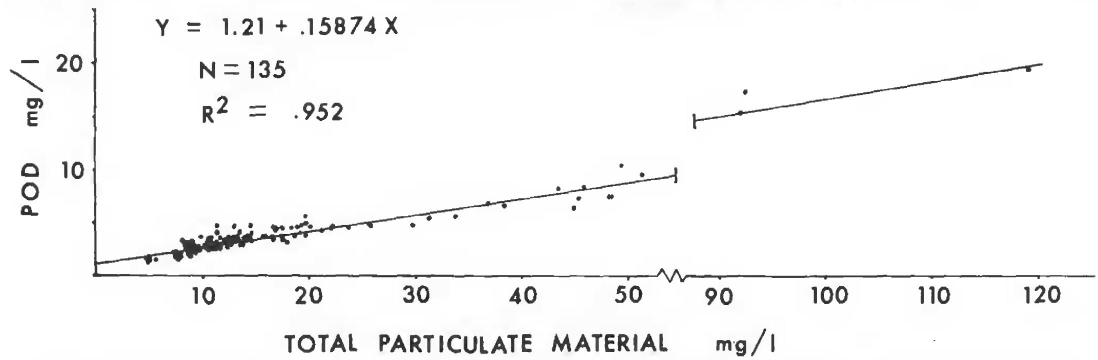

Figure 3. Relationship of particulate organic detritus (POD) to total particulate material in the water between May 1975 – April 1976.

to 6% net imports of particulate organic detritus. Nadeau (1972), Shisler (1975), Heinle and Flemer (1976), Woodwell et al. (1977) and the present study all reported net imports or at least no significant exports of suspended particulate organic detritus; while Teal (1962), de la Cruz (1965), Heald (1969), Day et al. (1973), Nixon and Oviatt (1973), Moore (1974), and Settlemyre and Gardner (1977) reported net exports. Some studies which reported high net exports are based on small data sets or on estimates rather than actual transport data. Only Moore's (1974) study, which reported net exports of 40% and 28% of the vascular productivity of two marsh systems, was based on the amount of data reported by Shisler (1975), Heinle and Flemer (1976), and Woodwell et al. (1977), who found net imports. No single factor (i.e., morphometry, hydrology, etc.) can explain the differences found between marshes with a net annual export and those with a net annual import of particulate organic detritus. All studies were made on tidal creeks except for Heald (1969) who studied a tidal river from which there was a constant supply of fresh water. Detrital export was expected in this system since there was a net export of water.

The concentration of particulate carbon in water has been determined by combustion (de la Cruz 1965; Heald 1969) and by analysis in a carbon analyzer (Moore 1974; Shisler 1975; Heinle and Flemer 1976; and Woodwell et al. 1977). Theoretically, there should be little difference between the two techniques. Because each of the references cited used the same technique throughout their study, net exports or imports cannot be attributed to differences in techniques.

Other studies (Day et al. 1973; Nixon and Oviatt 1973) report the flux only in terms of a predictive model, obtaining their values by subtracting all other potential pathways of energy loss from the total marsh productivity. This is a good approach, but until the role of the microbial community in marsh soils is quantified, this technique may overestimate the export.

Direct transport studies are deficient because they do not measure all of the tides during the year. The fewer tidal cycles examined, the greater the effect of one atypical tidal cycle on the annual budget. Conversely, the more tidal cycles examined (assuming random sampling), the more closely the estimates of total annual export or import approach the true value and the effect of one atypical day on the overall estimate is minimized. It is possible that some of these previous studies included data collected on atypical days or did not have a random sample of days including days when the weather was poor. When sampling was done on days preceded by fair weather, detrital export was observed in the study creek even though this is not what appears to be the usual pattern.

Another approach also provides strong evidence that tidal marshes do not export large amounts of organic material. In Georgia's estuaries, where a strong case is made by Odum and de la Cruz (1967) for a net tidal export of particulate detritus, Haines (1977) noted that the stable carbon isotope ratios of particulate detritus collected in Georgia estuaries did not resemble those of *Spartina alterniflora*. Stable isotopic ratios of *Spartina* carbon are different from the carbon ratios of phytoplankton or terrestrial detritus (Haines 1976). Carbon ratios of the plants are not changed to a significant extent as the carbon moves up the food chain and as it is degraded on the marsh (Haines 1977). The samples were collected from a tidal creek and a tidal river and were separated into five size fractions between 27 and 250 μm. The carbon ratios of all of these samples resembled those of organic matter of terrestrial or phytoplankton origin. Based on this and a mounting body of evidence from transport studies, Haines suggests a "re-examination of the assumption that the bulk of detrital carbon in Georgia's estuaries is derived from *S. alterniflora* production."

Examination of the sedimentary history of a marsh along with transport studies may be one of the best methods of determining long-term trends. The addition of 4.7 mm/yr organic material to the Flax pond marsh (Flessa et al. 1977) and estimates of the rate of sedimentation (Armentano and Woodwell 1975) substantiates Woodwell et al.'s (1977) contention that little carbon is exported from the Flax pond system. Another useful approach may be to examine the transport into and out of the entire estuarine system (Happ et al. 1977), as well as the transport from small creeks draining marshes. This approach requires information on the input of river systems which may be difficult to obtain.

More studies are needed to evaluate the dynamics and fate of suspended particulate detritus in the marsh-estuarine system. This study indicated that the amount of inundation of the marsh as reflected in the tidal height (variable [1] in Table 2), affected the particulate detritus concentration of water leaving the marsh. Therefore, differences in the amount of tidal inundation are suggested as an important factor with respect to particulate detritus transport reported in other studies. Tidal height was a measure of how much and to what extent the marsh was flooded. Tidal height does play a role in removing detritus from the water because marsh plants hinder or slow down the flow of water and produce conditions which may allow suspended material to leave the water column and settle on the substrate (Axelrad 1974). Once this material has settled, the current velocity necessary to resuspend the cohesive particles is greater than the current velocity necessary to transport these particles once they are in suspension. Particles smaller than 0.01 mm require as much current velocity to resuspend them as do particles over 2 mm (Hjulstrom 1939). The effect of the marsh biota may be important, particularly the filter feeders and amphipods as they remove detrital material from the water and deposit this as pseudofeces on the marsh. Many benthic amphipods also use detrital materials in the construction of their burrows (Thomas 1975). For this process to occur, water must reach these filter feeders, notably the pelecypods *Polymesoda caroliniana* and *Geukensia demissus*, which live on the marsh. Fungi, bacteria and protozoa on the mud surface may be important in retaining detritus on the marsh once it has settled. Conversely, the larger invertebrates and fishes tend to stir up the sediment. The grass shrimp *Palaemonetes pugio* and killifish, *Fundulus* spp., were observed "muddying the water" on many occasions during this study. None of these biotic factors can affect the concentration of detritus in the water unless the marsh floods. Table 1 indicates the variation of transport due to the irregular flooding that is characteristic of Gulf coast marshes.

Factors affecting the particulate detrital concentration of the waters also affect the overall transport of particulate detritus. Amphipods were generally more abundant in tidal marshes during cooler months (Thomas 1975), while fishes and larger crustacea were less abundant. Most of the cooler months exhibited a pattern of net import of particulate detritus (Table 1). Conversely, exports occurred during summer months when the larger fauna were most abundant. The higher concentration of particulate detritus near low tide was probably due to the greater concentration of mobile organisms per unit of water. The warmer water temperatures also increased their activity.

Other environmental factors also play an important role. Redfield (1972) noted that sedimentary material may be carried onto the marsh due to strong winds stirring up sediment in nearby shallow areas. Strong winds produce these conditions in the nearby bay. Heavy rainfall in the nearby watershed thus increases the potential flow of material to the St. Louis Bay system by the Jourdan and Wolf rivers (Figure 1). Locally heavy rainfall during low tides could also increase the detritus load of bay waters. Presumably, imports of detritus onto the marsh are caused by an increased amount of river-borne detritus in the water surrounding the marsh system.

Redfield (1972) suggested that marshes along the eastern coast of the United States are building up at the rate of 2.5 mm/yr. This requires the addition of material. The marsh in the present study appears to have a long-term record of clastics and organic material accumulation as evidenced by recognizable *Spartina* rhizomes buried 20 to 40 cm below the surface of the *Juncus* marsh. *Spartina* is characteristic of lower areas of this marsh (de la Cruz and Hackney 1977).

While it is possible to predict the concentration of particulate detrital material in the water that comes from marshes during ebb tide, based on information on tidal height, physical conditions of the water in the creek, time of the year and the abundance of organisms within the creek, the prediction of the concentration of particulate organic detritus in the water during flood tide is impossible. It probably depends greatly on the configuration and current patterns of the nearby estuaries and on such random factors as weather conditions and nearby river discharge.

This investigation suggests a net import of particulate material onto the marsh. Thus, it appears that high vascular plant productivity may not be the most important function of the marsh relative to the overall productivity of the estuarine system. Net export of particulate material occurs somewhat infrequently and is probably occasioned primarily by low concentrations of particulate detritus in the surrounding bodies of water. The marsh may serve as a holding area for material discharged by rivers, importing material during high river discharge periods and exporting material when that discharge is small. Thus, marshes may act as a control mechanism by removing materials from the water when the concentration of these materials is high in the nearby bays and rivers and then exporting these same materials when the concentration is low. The marshes, then, may dampen oscillations in the concentration of suspended materials in nearby bodies of water. This would tend to produce a more even release of material to offshore waters. Thus, even if a marsh exports very little of its own production as suspended particulate matter, it may be important in the regulation of overall export of material from estuaries.

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